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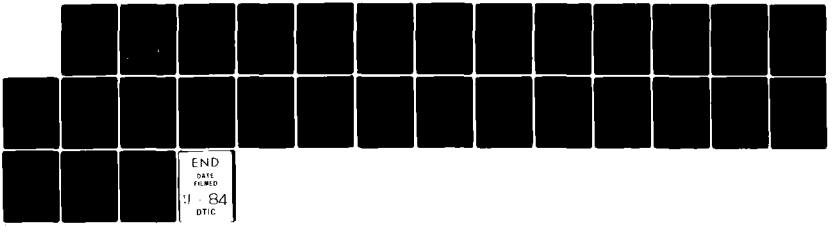

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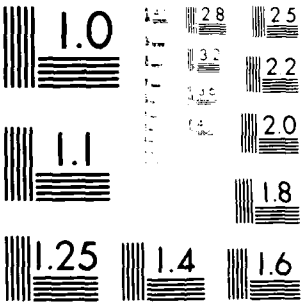
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REPORT NUMBER 3

Behavioral Interactions Under Noxious Environments

Final Report

James E. Barrett

June 30, 1980

Supported by

U. S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21701

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Department of Psychology
University of Maryland
College Park, Maryland 20742

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Summary

Behavior is subject to multiple environmental influences and can be altered in several different ways depending on how those influences occur, the individual's previous experience and other coexistent factors. This experimental research program has focused primarily on an analysis of the manner and extent to which prior experience and current environmental conditions control or affect behavior occurring predominantly under noxious environments. Research conducted during the first year of this contract was directed towards an exploration and understanding of the ways in which noxious events can control behavior. Those studies, utilizing electric shock as an aversive stimulus and squirrel monkeys as subjects, indicated that the same noxious stimulus can affect behavior in several quite different and unexpected ways. For example, although it had been known for some time that shock presentation would suppress (i.e., punish) responding and that organisms will respond to terminate or postpone presentations of recurring shocks, it was not widely known that response-produced shock would also maintain responding. Experiments conducted during the early phases of this program extended earlier work and documented other conditions in which behavioral performances were maintained by response-produced shock. The finding that under some conditions, animals would seemingly work to produce shock, served as the dominant theme and emphasis of much of the subsequent research conducted under this contract. Further experiments explored the potential interactions between performances controlled by both appetitive and noxious stimuli in an effort to determine how behavioral changes under one environmental condition contribute to a modification of behavior under existing as well as other more remote circumstances. In addition, other experiments examined the contribution of the organism's prior behavioral history to the development and maintenance of responding by response-produced shock. Finally, several experiments analyzed in detail the establishment of a number of different behavioral performances that were ultimately simultaneously maintained by different methods utilizing noxious events and by previously noneffective stimuli paired with those events. In these studies, it was possible to show that the same noxious environmental stimulus, electric shock, exerted multiple behavioral functions and that these different functions can exist at the same time. This research has provided extensive information on the multiple behavioral effects of noxious environmental events and has broadened our understanding of the manner in which behavior emerges and is established under environments that are essentially stressful or aversive in nature. Contrary to the early emphasis on the disruptive and deteriorating effects on behavior of noxious events, these experiments indicate that behavior controlled by recurring noxious stimuli can be extremely orderly, integrated and stable over extended periods of time. Taken as a whole these several findings provide a substantial basis for a reevaluation and, eventually, a more complete understanding of relevant factors involved in the fundamentally important behavioral processes of reinforcement and punishment.

Foreward

In conducting the research described in this report, the investigator adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences-National Research Council.

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Introduction

The broad objectives of this research program have consisted of an experimental analysis of behavior established and maintained under conditions where the dominant environmental features are noxious in nature. At the inception of these experiments those aspects of fundamental interest comprised an effort to investigate and understand the range of potential interactions occurring between behaviors controlled by noxious stimuli. In addition, experiments were planned that focused on the role of the organism's prior behavioral experience as a factor contributing to specific changes in current adaptiveness to noxious stimuli. This approach promised to generate information about the development and modification of behavior under noxious environmental conditions that could be directly related to both previous and current environmental factors.

A central theme in this research program has been the use of procedures in which responding is maintained by the response-produced delivery of electric shock. In view of the recurring emphasis on this technique throughout the program, the general procedure and significant earlier findings in this area are summarized below. The major results and conclusions of research conducted under this award are presented after this initial review.

Behavior maintained by response-produced shock

It is commonly known and has been documented experimentally countless times that the presentation of a noxious stimulus such as electric shock can suppress ongoing and subsequent behavior (punishment). On the other hand, behavior can be supported or maintained when it removes (terminates) or postpones (avoids) presentations of a noxious stimulus. These functions are consistent with a traditional dichotomy of appetitive events (e.g., food, water and certain drugs such as cocaine or heroin) and aversive events (e.g., electric shock, loud noise, physical injury) which differentially control behavior. Appetitive events are typically believed to instill behavior with much of its order, integration and malleability, whereas noxious events are often held to be responsible for behaviors characterized by disorder, chaos and aberrant persistence or rigidity. These findings and theoretical assumptions have supported a hedonistic classification of events which presumably have inherent behavioral properties and relatively immutable behavioral effects. It did not seem to matter greatly that these categorizations did not always square with common sense; instances in which food presentation did not function as a reinforcer or conditions under which shock delivery did were usually regarded as "paradoxical" in nature and were held to be transient and short-lived.

The first strong indication that these hedonistic dichotomies might not hold came from experiments by Kelleher and Morse (1968) showing that responding by squirrel monkeys could be maintained, apparently indefinitely, by the response-produced presentation of a rather intense (10 mA) electric shock. Significantly, the performances maintained by the scheduled shocks were characteristic of those maintained under comparable schedules of food presentation. Additionally, however, with the same monkeys, Kelleher and Morse also showed that the same shock that maintained responding under one

schedule would suppress responding under another. Thus, the same physical stimulus, shock presentation, maintained or suppressed responding in the same organism at the same time. The processes of reinforcement and punishment, typically regarded as event-related features, coexisted with the same event. Further work conducted shortly after that of Kelleher and Morse demonstrated the relative ease with which performances could be maintained by response-produced shock and showed that responding was affected by changes in shock intensity and schedule parameter value in a manner functionally equivalent to that occurring when the magnitude of food or parameter value of the food schedule was changed (McKearney, 1968, 1969). Further, comparable performances were also established in cats (Byrd, 1969), thereby extending the species generality of this finding.

Features of behavioral performances maintained by response-produced shock

Experiments demonstrating that responding could be maintained by shock presentation were important in several respects. First, they focused attention on the fundamental behavioral processes of reinforcement and punishment and placed the analysis of these processes in the broad experimental and conceptual framework of schedule-controlled behavior. It had been emphasized for some time that several concepts in psychology (e.g., motivation and drive) could be more appropriately viewed as schedule-dependent phenomena (Morse, 1966). The maintenance or suppression of behavior by shock presentation has now been shown in several studies to depend directly on the schedule under which shock is delivered (Barrett and Glowa, 1977; Kelleher and Morse, 1968; McKearney, 1972).

In addition to emphasizing the importance of current schedule conditions, experiments focusing on this problem have also been responsible for elucidating other factors that play a role in shock-maintained responding and which are, unquestionably, of widespread significance. The early experiments on and interpretations of responding maintained by response-produced shock stressed forcefully the importance of the organism's prior experience for the eventual establishment and maintenance of responding by shock delivery (Kelleher and Morse, 1968; Morse and Kelleher, 1970, 1977). The maintenance of responding by response-produced shock appeared to require certain pre-existent features such as an ongoing rate of responding which could be modulated by the scheduled response-produced shock. This initial level of responding could be elicited (Morse, Mead and Kelleher, 1967), it could be generated by initial exposure to an avoidance or shock-postponement schedule (McKearney, 1968) or by prior training under a food-presentation schedule (Kelleher and Morse, 1968). All of these procedures appeared to ensure the development of some relatively high level of ongoing behavior which could then be modified and eventually maintained solely by response-produced shock.

An emphasis on the schedule of reinforcement and prior experience provided the general framework, that of the processes of reinforcement and punishment, within which to place and evaluate these findings. Rather than being paradoxical and anomalous, the results of these several experiments could relatively easily be incorporated into the pervasive and fundamental processes controlling behavior. Environmental events do not have static and immutable behavioral properties but rather depend intimately on other factors for any one of several effects to become apparent.

Commonalities among behavioral events

The dual (i.e., reinforcing and punishing) behavioral effects characteristic of electric shock are not unique to this stimulus but are features displayed by a variety of salient behaviorally relevant events. Premack (1965, 1971) has emphasized for some time the reversibility of the reinforcement relation and has demonstrated experimentally that the opportunity to engage in one behavior can be reinforcing or punishing depending on certain antecedent conditions. It has also been demonstrated that animals will either respond to produce or will avoid electrical stimulation of the brain depending on how it is scheduled (Steiner, Beer and Shaffer, 1969). Further, the same drug that serves as a reinforcer under one condition will suppress or maintain avoidance behavior under another (Wise, Yokel and Dewit, 1976; Woods, Downs and Carney, 1975). The latter findings are significant because they extend the generality of multiple behavioral effects to events other than shock and because they emphasize the importance of behavioral experience in obtaining these effects. Thus, it can be concluded that electric shock is not unusual in exerting multiple behavioral effects. Events that effectively control behavior are not necessarily imbued with singular unmodifiable properties that are independent of other factors.

The wide variety of ways in which behavior can be controlled by noxious events and the pervasiveness of such environmental conditions in both military and non-military environments provides a suitable experimental means and an intact justification for the research to be described in the remaining sections of this proposal.

General Experimental Methods

Healthy adult squirrel monkeys (Saimiri sciurea) were used as subjects in all of these studies. The monkeys were maintained in individual cages except when removed for daily one-to-three-hour sessions. In some cases body weight was reduced to 80 percent of the unrestricted feeding levels.

Experimental studies were conducted in a primate-restraint chair furnished with response devices, visual stimuli and methods of delivering food and electric shock. The distal end of the tail was shaved and, during experimental sessions, was held immobile by a small stock. Prior to each session the tail was massaged with EKG-sol electrode paste. Electric shock was delivered from a 650 V a.c. source to two brass electrodes that rested on the shaved portion of the tail. Shock duration was 200 msec with the intensity varied, depending upon the specific experiment. During the session the chair and restrained monkey were placed inside sound-attenuating cubicles that were also equipped with white masking noise.

In experiments using shock postponement or avoidance schedules, shocks were usually scheduled to occur every 5 seconds; a response postponed shock for 25 seconds. Unless otherwise noted, this procedure served as the initial phase for all experiments in which responding was maintained by shock presentation. It should be noted, however, that training under shock-

postponement schedules is not necessary for the development and maintenance of responding by response-produced shock (cf., Kelleher and Morse, 1968; McKearney and Barrett, 1978; and Morse and Kelleher, 1977). In some experiments the shock-postponement schedule was removed upon introduction of the schedule of shock presentation, whereas in other studies both schedules were in effect simultaneously for a brief period (5-10 days) prior to the removal of the avoidance schedule.

Changes in experimental conditions were made when responding was stable over at least a one-week period. Usually a condition was in effect for at least 15-20 sessions before changes in the schedule were made.

Reinforcement and Punishment of Behavior by Response-Produced Electric Shock

As mentioned in the Introduction to this report, one of the more dramatic findings of the initial work by Kelleher and Morse was a demonstration that shock presentation could either maintain or enhance responding or, conversely, could suppress responding depending on how it is scheduled. Since one of the primary objectives in this research program was to focus on interactions between sequentially- and simultaneously-occurring behaviors differentially controlled by shock presentation, experiments were conducted in which these performances were maintained under multiple and concurrent schedules. Typically, under a multiple schedule different performances are maintained by different schedules, each of which is correlated with a distinctive stimulus. Only one schedule (and stimulus condition) is in effect at a particular time and exposure to the different conditions is, therefore, sequential. Despite the temporal separation, it is not uncommon to find that a modification of behavior under one of the conditions also affects performance under the other (unaltered) condition.

Under concurrent schedules two or more schedule conditions are simultaneously in effect. Although there are different specific ways of arranging concurrently scheduled events, we have concentrated solely on experimental procedures in which two response devices are available and responding on each manipulandum is correlated with a particular schedule and/or consequence. The concurrent schedule procedure, together with multiple schedules, was employed to develop different performances and then focus on the nature and the extent of potential interactions occurring under conditions where behavior is controlled sequentially and simultaneously by both noxious and appetitive events.

Multiple schedules

Figure 1 (page 9) shows the wide variety of ways in which we have used shock presentation to develop and study performances under both single component and multiple schedules. This figure also illustrates how events as different as food and shock can maintain essentially identical performances when these events are scheduled similarly. The top panel in Figure 1 depicts characteristic rates and patterns of responding maintained under a

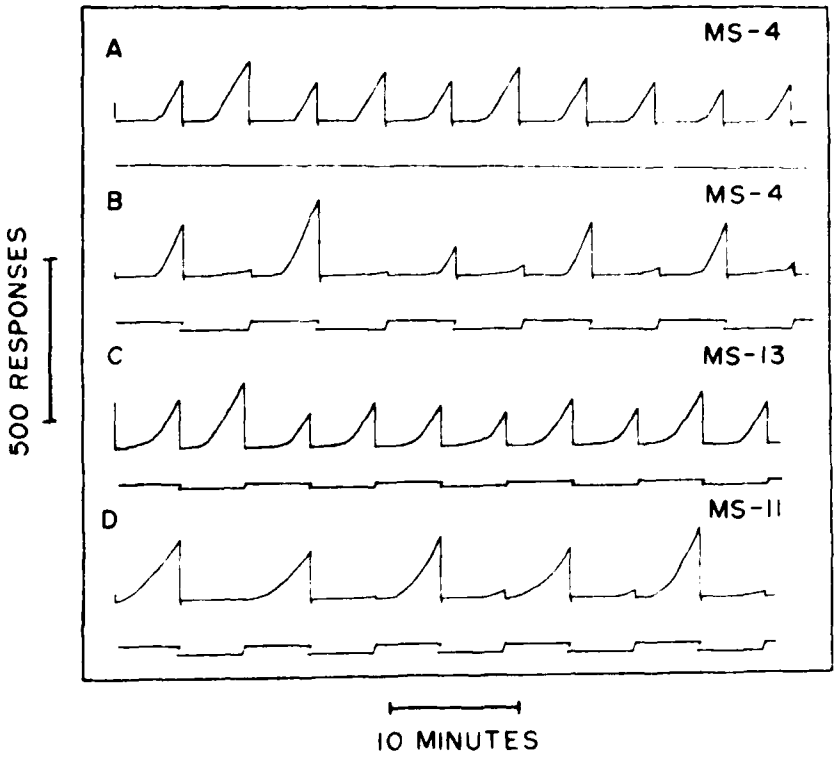

FIGURE 1

Cumulative response records summarizing performances under various schedules of food and shock presentation. These records of lever pressing by squirrel monkeys demonstrate the multiple effects shock can have on behavior. Ordinate: cumulative responses; abscissa: time. In all records the pen reset to baseline at the end of each scheduled condition. Panel A: responding maintained under a 5-min fixed interval schedule of food presentation; i.e., the first response after 5-min elapsed delivered food. Panel B: each 30th response during alternate components produced a 5 mA shock which suppressed responding (punishment). Periods of punished and unpunished responding during the session were indicated by different stimuli. In the records shown above, those portions of the session where responding was punished are indicated by the displacement of the event pen. Panel C: responding maintained under a multiple schedule where either food or shock was delivered after 5-min elapsed. Different stimuli were correlated with food or shock presentation. Note that the patterns and rates of responding were comparable regardless of whether food or shock presentation maintained responding. Panel D: responding maintained and suppressed by shock presentation. During one portion of the session (event pen up), the first response after a 5-min period produced a 9 mA shock; this event maintained high response rates. During the second segment of this session, the first response after a 5-min period produced food but also, during this stimulus, each 30th response produced a 9 mA shock that suppressed responding. Thus, the same shock stimulus was serving as a reinforcer or a punisher, depending on the stimuli present and on the schedule in effect at that time.

5-minute fixed-interval schedule where the first response after 5 minutes has elapsed produced food. There is an initial pause in the early portion of the interval followed by a transition to a relatively high rate of responding that is sustained until food delivery. In the second record, Panel B, a multiple schedule was in effect. During both stimulus conditions responding was maintained under 5-minute fixed-interval schedules of food presentation. However, during one component, associated with a pair of white lights, each 30th response also produced a 5 mA shock which suppressed responding considerably (punishment, shown by the period in the record where the lower line is displaced). In the third record, Panel C, shock presentation functioned as a reinforcing rather than as a punishing stimulus. This record depicts performance under a multiple schedule where a response after 5 minutes produces either food or electric shock depending on the prevailing stimulus. Performances maintained by shock delivery, indicated by the offset line, are remarkably similar to those maintained by food in both the rate and patterning of responding over the course of the 5-minute interval.

The last record in Figure 1, Panel D, shows the maintenance and suppression of responding by shock under a multiple schedule. In this experiment responding during one component was maintained under a 5-minute fixed-interval schedule of response-produced shock (lower line not displaced). During the alternate component, responding was maintained by food, also under a fixed-interval 5-minute schedule but, additionally, each 30th response produced the same shock that was delivered during the other component. Under the fixed-interval schedule responding was maintained by the same shock that, during the alternate component, suppressed responding when presented under the fixed-ratio schedule. This result demonstrates the dual behavioral effects that shock presentation can have and suggests that these different effects are dependent on the schedule under which shock is presented.

The finding that, under different conditions, shock can function as a reinforcer and as a punisher in the same organism is strong experimental testimony to the range of diverse behavioral effects that certain stimuli can have. These performances were not fragile or poorly maintained, but were stable over at least a two-year period without attendant loss of either the reinforcing or punishing efficacy. In addition, these experiments with multiple schedules in which responding is both maintained and punished by response-produced shock indicate that monkeys responding to produce shock are not insensitive to its "more typical" (i.e., punishing) effects. Neither reinforcement nor punishment are restrictive categories that exclude certain types of events. Instead, these processes appear, in part, to be phenomena dependent on the schedule, the organism's previous experience and current environmental conditions.

Regardless of how the maintenance and suppression of behavior by shock presentation are eventually interpreted, it is quite clear that such findings continue to challenge traditional beliefs. Additional research conducted under this award has been able to address some of those issues and provide alternative accounts. These will be discussed in subsequent sections of this report.

Concurrent schedules: reinforcement and punishment

A rather substantial portion of our research efforts have consisted of several experiments in which responding has been maintained simultaneously by different schedules of shock presentation. One experiment was directly related to the multiple schedule study just described in which responding was sequentially maintained and punished. Under the concurrent schedule two levers were available. Responses on one lever produced shock under a 3-minute variable-interval schedule; responses on the other lever produced food under an identical variable-interval schedule, but every 30th response also produced shock. Response rates under the variable-interval schedules of shock or unpunished food presentation were characteristic of performances under these schedules generally in that steady rates of responding were maintained throughout the session (top records, Figure 2, page 12). When the 10-response shock-presentation schedule was added, food-maintained responding was decreased considerably (lower left panel, Figure 2), whereas responding was actually increased on the lever where responses produced shock (lower right panel, Figure 2).

In addition to extending the generality of the reinforcing and punishing properties of shock presentation to a different schedule condition, this study is illustrative in other respects. Again, establishing shock as a reinforcer does not appear to diminish its efficacy as a punishing stimulus and vice versa. Performances under the concurrent schedules appear quite independent, although subtle interactions inevitably exist. Furthermore, this study and other experiments conducted during the course of this contract obviate the criticism that with only a single manipulandum available the monkeys have no alternative but to respond. Under the initial phase of this study responding was maintained on both levers by food and shock; merely providing a second response device which arranges for food delivery is not sufficient to eliminate responding maintained by shock. Other work in this laboratory has indicated that responding can be maintained by response-produced shock when up to four levers are simultaneously available and responses on only one of these levers produce shock.

Concurrent schedules: shock presentation and termination

In another experiment responding was maintained on one lever which produced electric shock and was simultaneously maintained on a second lever where responding terminated the shock schedule and shock-associated stimuli for a one-minute period. Shock was presented according to a 3-minute variable-interval schedule which engendered steady rates of responding. The stimulus and shock schedule were terminated according to a 3-minute fixed-interval schedule; the fixed-interval schedule maintained characteristic positively-accelerated rates and patterns of responding (Figure 3, page 13).

The distinctive performances developed and maintained under the concurrent shock-presentation and stimulus-shock termination schedules have recently been studied using intravenous cocaine as a reinforcer (Spealman, 1979). In this experiment responding on one lever by catheterized squirrel monkeys produced an intravenous delivery of cocaine under a variable-interval

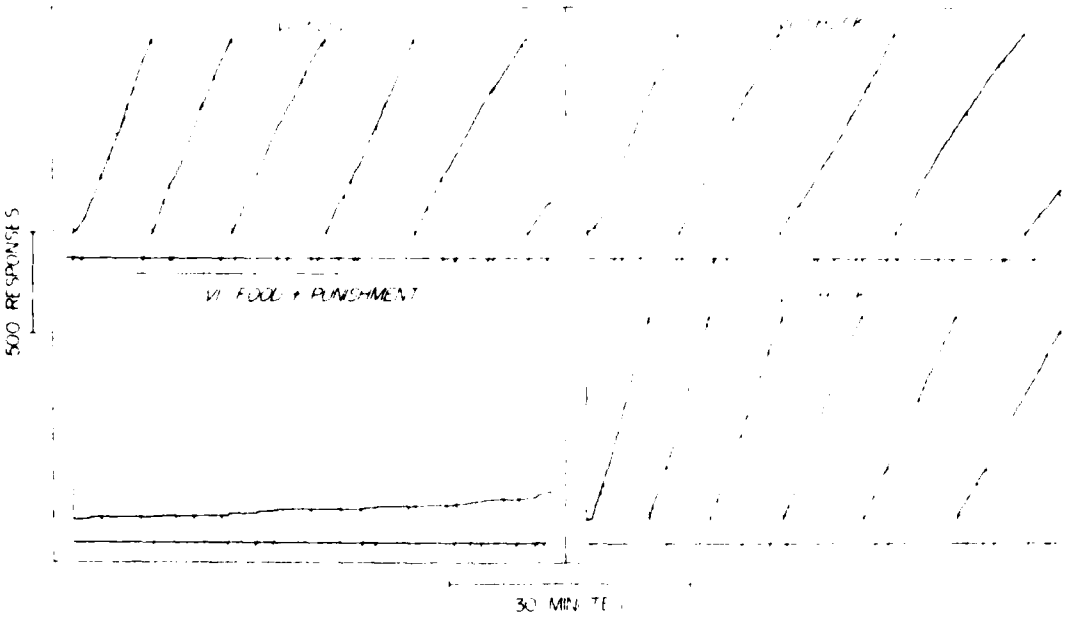

FIGURE 2

Reinforcement and punishment of behavior under a two-lever concurrent schedule. Responses on one lever produced a 1.5 mA shock on the average of every 3 minutes (variable-interval schedule, top right record). Responses on a second lever initially produced food under a similar schedule (top left record) and subsequently, every 10th response also produced a 3 mA shock; food-maintained responding was suppressed under this condition (bottom left record). However, responding was still maintained by the 3 mA shock under the variable-interval schedule (lower right). Changes in shock intensity unfortunately prevent direct comparisons between performances maintained by shock before and after responding was punished. Diagonal marks on the cumulative response record denote food or shock presentation; marks below each of the top records indicate presentation of the alternate event, whereas marks below the bottom records signify shock presentation under the 10-response schedule. The pens returned to baseline after approximately 1100 responses.

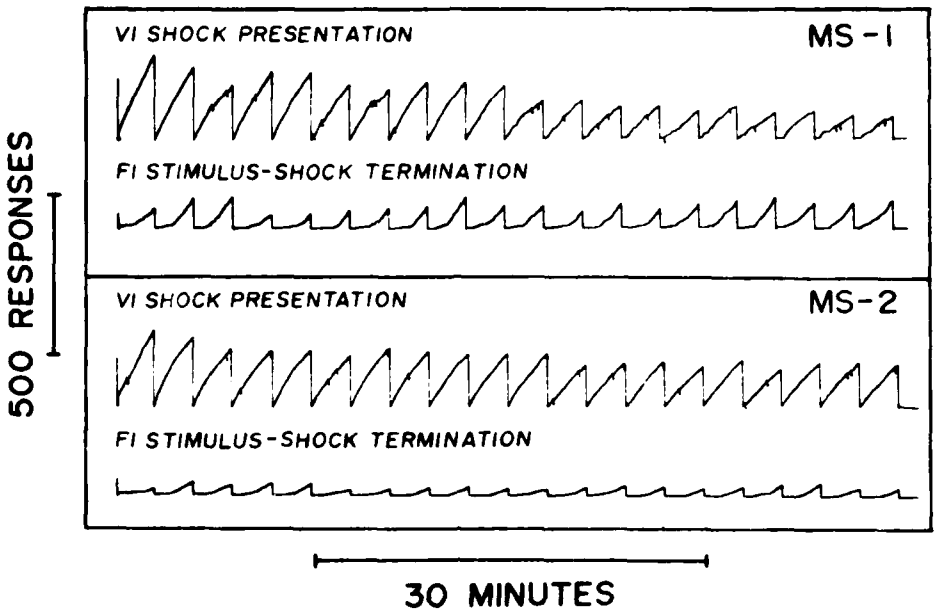

FIGURE 3

Cumulative response records showing schedule-appropriate rates and patterns of responding during the ninety-fifth session under the two-lever concurrent schedule for each monkey. Responding on the right lever produced a 7 mA electric shock on the average of once every 3 minutes (variable interval shock presentation; upper record in each panel). A response on the left lever after 3 minutes terminated the schedule of shock presentation and extinguished the white light in the chamber for a 1-minute timeout period (fixed-interval stimulus-shock termination; lower record in each panel). During timeouts, responding had no scheduled consequences and the recorder did not operate. Shock presentations are indicated by diagonal marks on the upper record in each panel. The pens reset at the end of each timeout period.

schedule; responding on a second lever under a fixed-interval schedule terminated the prevailing stimuli associated with cocaine injection and presented cocaine injections for a one-minute period. In all important respects, the performances maintained under this concurrent schedule with cocaine were comparable to those maintained by shock shown in Figure 3. This finding, with a conventionally regarded potent reinforcer, testifies to the point that shock may be less unique than many have presumed.

Finally, these results question the typical distinction frequently made between positive and negative reinforcement. Under many circumstances organisms terminate noxious environmental events and associated stimuli. This behavior has typically been classified as escape and the process termed negative reinforcement (Skinner, 1953). The process of negative reinforcement refers to increases in responding that result from the termination of an event, and positive reinforcement refers to increases in responding that result from the presentation of an event. It is also tacitly assumed that events which function as either positive or negative reinforcers belong to exclusive categories and that the behavioral effects of these events depend on their intrinsic properties. The findings described above with shock and cocaine emphasize the difficulty involved when attempting to assign behavioral properties to events independently of the effects those events have on behavior. Environmental events can exert multiple behavioral effects and a classification of those events cannot be based exclusively on a priori considerations about the nature of those events.

Concurrent schedules: shock presentation and shock postponement

In a related study, interest was directed at examining the question of whether responding could be developed under a schedule of response-produced shock when initial avoidance training was given with a topographically different response. Squirrel monkeys were first trained under a shock-postponement or avoidance schedule using a chain-pulling response. A lever was also present during the initial phases of this experiment but few responses occurred when lever responding either had no consequence or later, when the first response after 3 minutes produced shock. The chain-pulling response, however, developed quite rapidly and was maintained at a steady rate that postponed almost all shocks.

When the chain and avoidance schedule were removed, however, lever responding developed quite rapidly and was subsequently maintained under the fixed-interval response-produced shock schedule (top panel, Figure 4, page 15). Later, when the avoidance schedule and chain were reintroduced, responding was maintained simultaneously on the two manipulanda under both the shock-postponement and shock-presentation schedules (bottom panel, Figure 4). Under the fixed-interval shock-presentation schedule, responding was characteristically positively accelerated, whereas under the avoidance schedule responding occurred at a steady rate. Thus, a new and topographically different response (lever responding) was developed and maintained by response-produced shock after prior training of a different response (chain pulling) under a shock-postponement schedule. A history of responding maintained by shock postponement, even though this experience occurred with a different response, was sufficient for the development and eventual maintenance of responding by shock presentation.

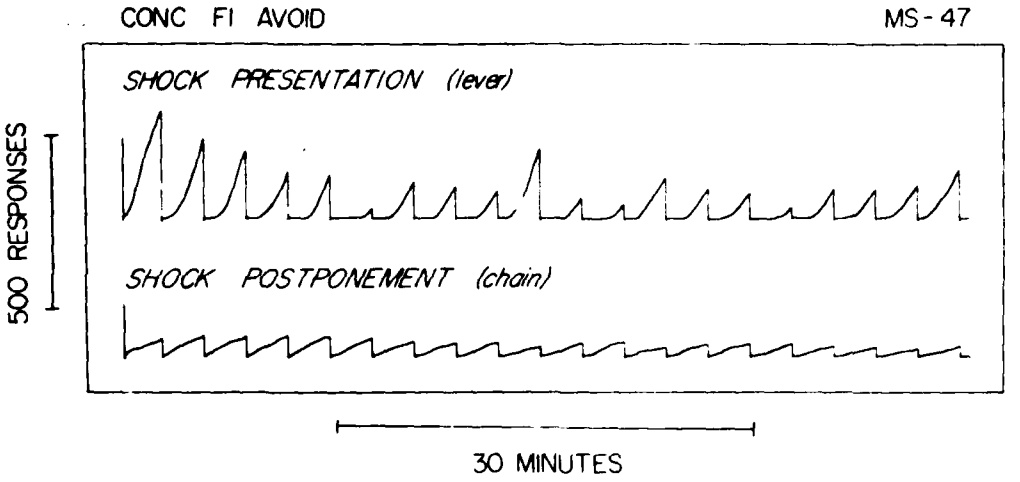

FIGURE 4

Cumulative response records showing lever-pressing performances maintained under concurrent schedules of shock presentation and shock postponement. Responding was first developed under a shock-postponement (avoidance) schedule in which a chain-pulling response postponed shock for 45 seconds. Subsequently, the chain and avoidance schedule were removed; responding developed and was maintained on the lever under a 3-minute fixed-interval (FI) schedule. Responding was then maintained under both schedules when the chain and avoidance schedule were reintroduced and the fixed-interval schedule remained in effect. Under the fixed-interval schedule responding was positively accelerated throghout the interval, whereas steady rates of responding were maintained under the avoidance schedule. The pens returned to baseline after each shock under the fixed interval. There was no timeout period separating the individual intervals.

In further work under this concurrent schedule the effects of separately removing the shock-presentation or shock-postponement schedules were studied. Figure 5 (page 17) summarizes the effects on responding of separately extinguishing one concurrent performance. With both monkeys response rates were higher under the fixed-interval schedule than under the shock-postponement or avoidance schedule (Panels A). When the avoidance schedule was removed, rates of chain pulling declined, although low levels of responding on the chain continued to occur (Panels B). With MS-46 lever pressing that produced shock was increased slightly when chain pulling declined, but this did not occur with MS-47. Chain pulling increased when the shock-postponement schedule was reinstated (Panels C) and was unaffected when the shock-presentation schedule was subsequently removed (Panels D). Lever pressing, however, declined substantially when this response no longer produced shock.

As in the previous experiments described in this report the concurrent performances show a rather remarkable degree of independence. Each performance is well-differentiated and relatively unaffected by modification in performance occurring under the alternate schedule, even though these are occurring simultaneously.

Concurrent schedules: food and shock presentation

An additional series of experiments has focused on establishing performances under concurrent fixed-interval or variable-interval schedules of food and shock presentation. Squirrel monkeys in this study responded on two simultaneously available levers, one of which produced food and the other shock. In one phase food and shock were scheduled under 3-minute fixed-interval schedules, whereas in a second phase these events were arranged under variable-interval schedules. Figure 6 (page 18) shows these concurrent performances and indicates that responding can be easily developed and maintained under schedules of this type. It is worth mentioning again that this type of schedule provides ample opportunity for responding to occur exclusively on one lever. The finding that responding was distributed on both levers would appear definitively to preclude arguments that emphasize the possibility that shock maintains responding only because a single manipulandum is available or that the animals respond for any form of stimulation.

Maintenance of Behavior by Stimuli Paired With Shock Presentation

Within the past few years new techniques have been developed and studied that permit behavioral performances to be maintained over extended periods of time by previously non-effective stimuli (conditioned reinforcers). These procedures, termed second-order schedules (Kelleher, 1966), have been used extensively in the analysis of drug-seeking behavior where protracted responding of experimental animals has been maintained by visual stimuli only remotely paired with a drug injection. Second-order schedules have been extremely beneficial in bringing an experimental analog of drug addiction into the laboratory where it can be studied in some detail (Goldberg, 1975; Kelleher, 1975).

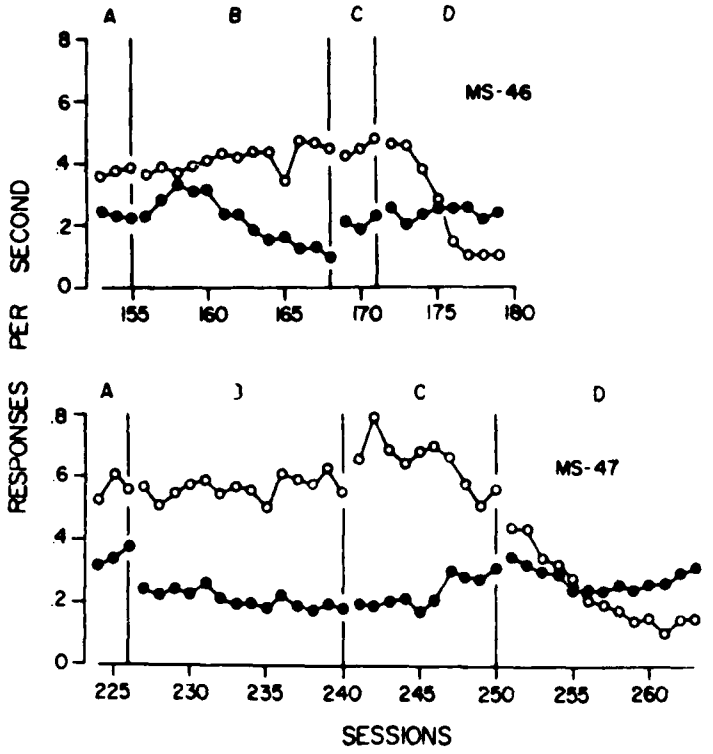

FIGURE 5

Effects of extinction under the concurrent fixed-interval 3-minute shock-presentation, shock-postponement (avoidance) schedule. Unfilled circles denote lever pressing maintained by the fixed-interval 3-minute schedule of response-produced shock; filled circles refer to chain pulling maintained by the shock-avoidance schedule. Panel A: last three sessions under the concurrent fixed-interval 3-minute schedule; avoidance schedule before the avoidance shocks were removed (Panel B); Panel C: concurrent fixed-interval 3-minute, shock avoidance; Panel D: removal of the fixed-interval 3-minute shock-presentation schedule.

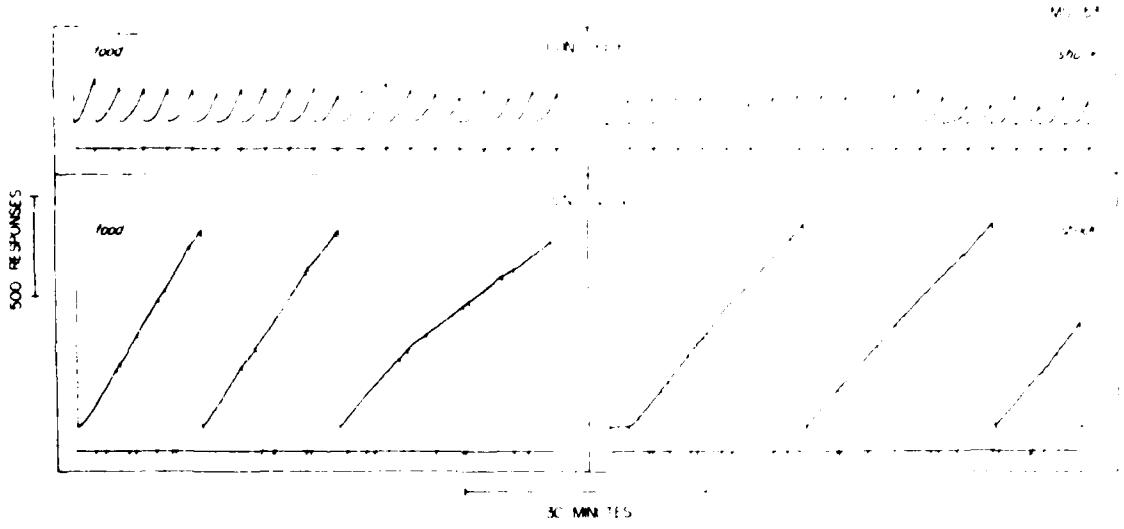

FIGURE 6

Cumulative response records of performances maintained simultaneously under concurrent variable-interval (VI) or fixed-interval (FI) schedules of response-produced food and shock. Two levers were available and responding on one produced food, whereas responding on the other delivered shock. Both food and shock schedules were in effect at the same time and were arranged independently. The top records show performances on each lever under the concurrent FI schedules. The recording pen reset when a response produced that event. Marks below the records denote presentations of the alternate event. Under both fixed-interval food and shock schedules responding was positively accelerated, whereas under the variable-interval schedules, responding maintained by both events occurred at a steady rate. Diagonal marks on the VI records denote food (left) or shock (right) delivery. The pens in the lower records reset after approximately 1100 responses.

Briefly, a second-order schedule typically arranges for responding to produce a brief (1-3 second) stimulus according to a particular schedule. Completion of this schedule requirement is then treated as a unitary response which is then also reinforced with the maintaining event according to a specific schedule. For example, in an experiment to be described below the first response after 3 minutes elapsed produced a 2-second change in the visual stimulus illuminating the monkey's chamber (fixed-interval 3-minute or FI 3-min schedule). After completion of the tenth fixed interval the 2-second stimulus change was followed by food or, with separate monkeys, presentation of electric shock (fixed-ratio 10-response or FR 10 schedule). Under this procedure then, food or shock would not be delivered for at least a half-hour after the session began.

Second-order schedules of this type, comparing responding maintained by food or shock presentation permit an analytical extension of the range of conditions under which noxious and non-noxious stimuli exert comparable effects on behavior. Figure 7 (page 20) illustrates the similar performances that can be maintained by food and shock under the type of second-order schedule just described. In this study, patterns of responding maintained by the brief stimuli presented under the fixed-interval schedules were comparable to those found under fixed-interval schedules where the maintaining event occurs upon completion of each schedule unit. We have also developed comparable performances under similar schedules when responding produces a stimulus paired with the termination (timeout) of a schedule in the presence of which shocks can occur.

The maintenance by noxious events of orderly responding over extended periods provides still another illustration of the broad range of conditions under which noxious events and associated stimuli are capable of controlling performances similar to those maintained by more traditional reinforcers. This conclusion is supported further by the experimental findings depicted in Figure 8 (page 21). In this experiment responding was maintained by food, shock presentation or intramuscular cocaine under a different type of second-order schedule than that just described. In this case every tenth (or thirtieth) response produced the 2-second stimulus (fixed-ratio 10 or 30 schedule) and the first stimulus after 30 minutes had elapsed resulted in delivery of the maintaining event. Although pauses following the brief stimuli were longer under the shock schedule, performances under these schedules were essentially similar despite the different types of maintaining consequences. The longer pause with shock as the maintaining event is probably due to the longer fixed-ratio value under this condition. Most importantly, these schedules maintained responding over fairly extensive time periods by the presentation of stimuli paired with the maintaining event only at the end of the session.

Responding maintained under second-order schedules offers several advantages over that maintained under more basic schedules. Particularly in experiments where one is interested in examining the effects of other variables on behavior, it is often important to prevent the direct interaction of that variable with the maintaining event. For example, one active area of interest in psychopharmacology is the effect of administering certain drugs on behavior actually maintained by drug administration (e.g.,

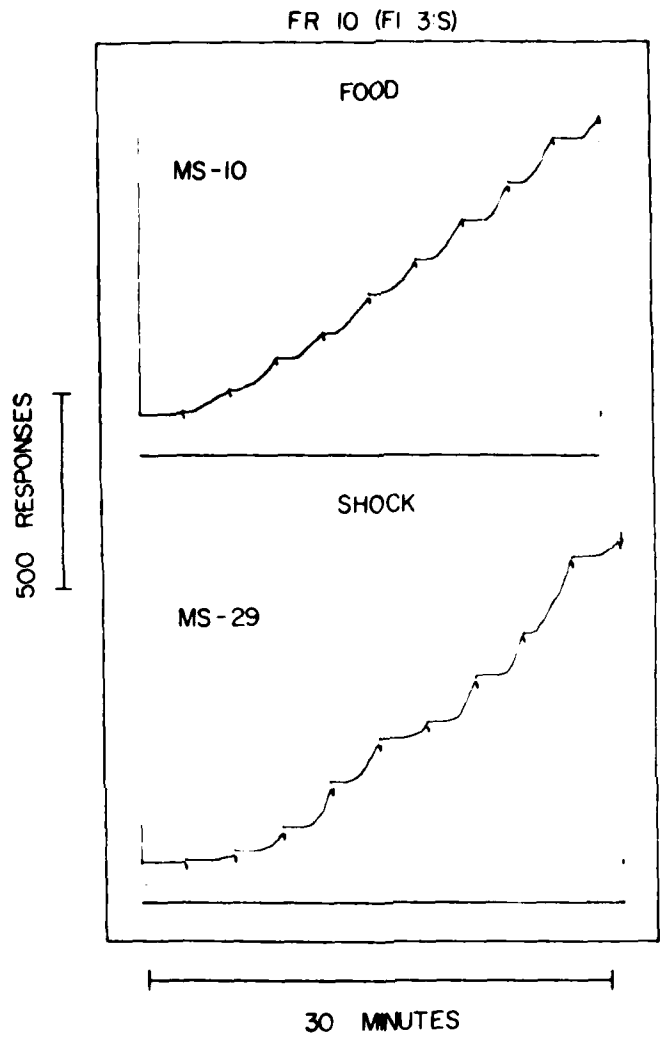

FIGURE 7

Cumulative records of performances under second-order schedules of food or shock presentation [FR 10 (FI 3-min:S)]. Under this schedule the first response after 3 minutes produced a 2-second brief stimulus (denoted by diagonal slashes on the records). Following completion of the tenth fixed-interval the brief stimulus was followed by food or shock delivery. Note the comparable performances maintained by these two events.

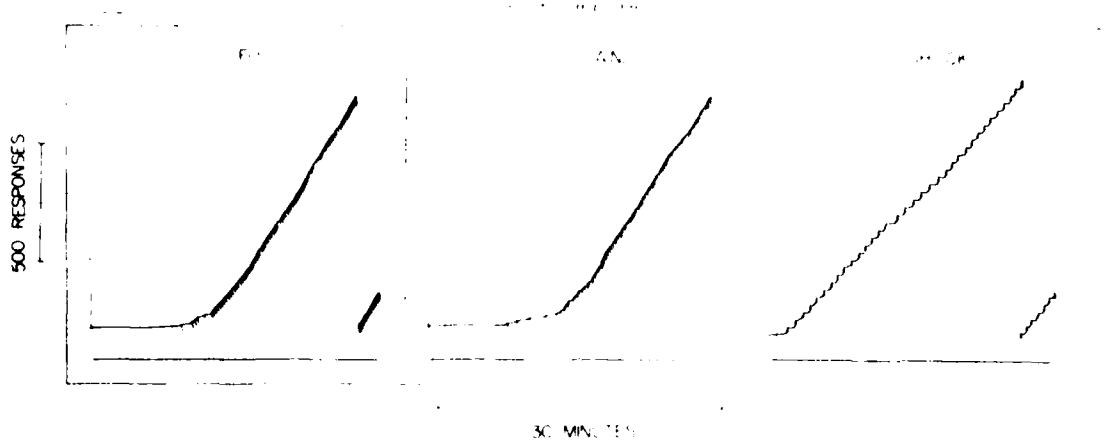

FIGURE 8

Cumulative response records of performance under second-order schedules of food, shock or cocaine presentation when these events occurred only at the end of the session. Under each condition every tenth (30th for the monkey under the shock-presentation schedule) response produced a brief 2-second visual stimulus (fixed-ratio or FR schedule). The first stimulus after 30 minutes had elapsed was followed by the maintaining event (fixed-interval or FI 30-minute schedule). The entire schedule is designated FI 30-min (FR:S). The brief stimulus presentations are indicated by the diagonal slashes on each record. The pen returned to the baseline upon delivery of food or shock (8 mA). Cocaine (2 mg) was injected intramuscularly immediately following the first stimulus after 30 minutes elapsed. The pauses after the brief stimuli were longer under the shock-presentation schedule; this is most likely due to the higher FR value.

the effects of lithium or chlorpromazine on behavior maintained by cocaine). Since it is not desirable to have the two drugs interact directly, second-order schedules where the maintaining drug occurs only at the completion of the session provides a useful means of circumventing this problem. The drug of interest can be injected before the experimental session begins, thereby allowing an assessment of the direct effects of this drug on drug-maintained performance without the contaminating influence of combined drug effects.

Subsequent experiments with noxious stimuli may also benefit from more extensive analyses of performances maintained under second-order schedules of response-produced shock. For example, it has been suggested that the delivery of shock directly elicits responding which may account for the maintenance of performances under schedules of this type. Since shock does not occur until the end of the session under second-order schedules of the type just described, this aspect cannot account for the maintenance of responding by response-produced shock.

Conclusions

The several experiments described in this report show the wide range of behavioral effects that a noxious stimulus such as electric shock can have. Response-produced shock can suppress behavior, in which case it functions as a punisher, or it can maintain or enhance responding, in which case it functions as a reinforcer. Significantly shock can function in these different capacities at the same time (Barrett, 1977; Barrett and Glowa, 1977; Kelleher and Morse, 1968; McKearney, 1972). Experiments conducted under this contract have elaborated still other conditions under which shock presentation maintains one response while, simultaneously, responding is also maintained by termination of that shock and associated stimuli (Barrett and Spealman, 1978) or by postponement of the same shock that is otherwise presented (Barrett and Stanley, 1980). This is an impressive array of effects for a single stimulus that was at one time considered to exert relatively singular effects on behavior.

These findings indicate that the behavioral effects of environmental stimuli are complex and multiply determined. Conditions under which a noxious stimulus such as shock maintains responding should not, however, be regarded as paradoxical or as exceptional instances to more general behavioral processes. Instead, these findings should force attention away from categorically restrictive event classes which presumably, but wrongly, have invariant behavioral effects. In the future, attention should focus on the fundamental processes responsible for controlling behavior and the general principles which account for these effects.

Research conducted under this contract, as well as that reported by others, has emphasized the important role of the organism's behavioral history and current environmental conditions. A great deal of attention has been given these variables with regard to food-maintained responding and, unfortunately, it is often assumed that similar factors hold for other

events when, in fact, this may not be the case. The properties of an effective reinforcer do not reside in the particular event but in its effects on behavior. These effects are a function of prior experience and prevailing environmental conditions which are dynamic in nature. For example, appropriate deprivation levels are initially necessary for food to function as a reinforcer and to permit the shaping and differentiation of new behavior. These factors may become less critical later, once appropriate performances are established. With other events different preliminary conditions are almost certain to be essential. In order for behavior to be maintained by response-produced shock, for example, some ongoing level of responding may be necessary which, as with food, can then be modulated by the presentation of that event following a response. It is certain that other reinforcers may require still different preliminary conditions for them to function effectively. The extraction and clarification of those variables will yield general principles of widespread importance that will inevitably promote a better understanding of the control of behavior by both noxious and non-noxious events.

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